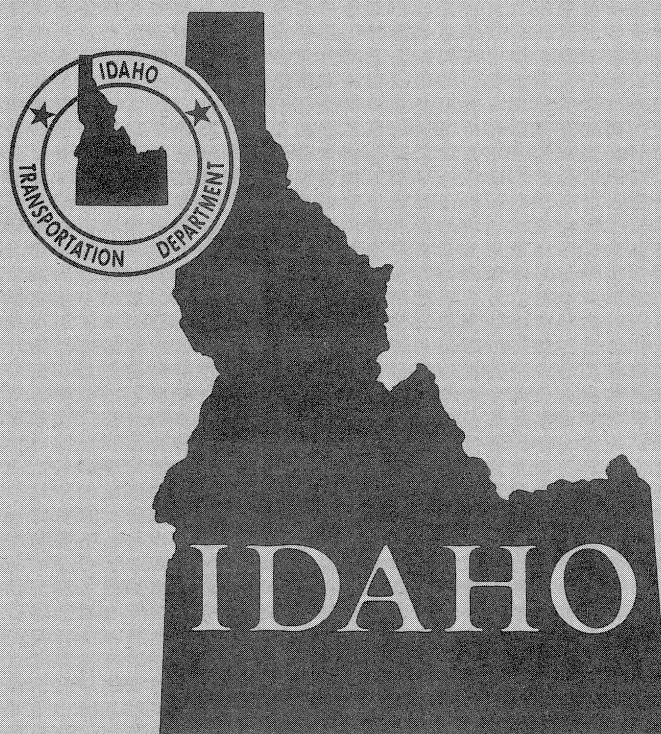
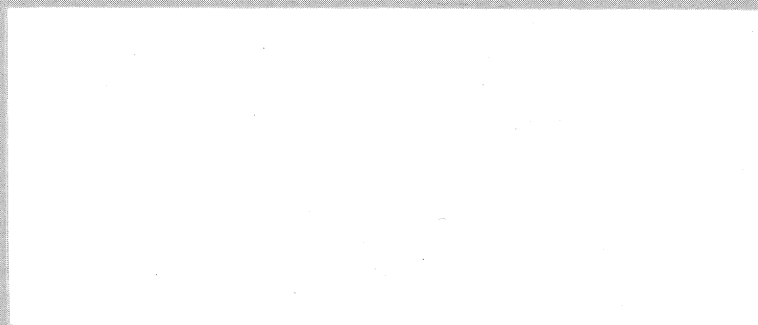


# TRANSPORTATION DEPARTMENT DIVISION OF HIGHWAYS



**IDAHO TRANSPORTATION DEPARTMENT**

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**MATERIALS and RESEARCH SECTION**

CATHODIC PROTECTION OF BRIDGE DECKS

ITD-RP071

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Research Project 71

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August 9, 1977



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# D I S C L A I M E R

The findings, opinions, conclusions and recommendations contained in this report are those of the author and do not necessarily reflect official policies of the Idaho Division of Highways.

## FINAL REPORT RESEARCH PROJECT 71

### Cathodic Protection of Bridge Decks

#### FORWARD

This project was originated at the request of Mr. Robert B. Jarvis, P. E., Bridge Design Supervisor, and has been developed based primarily upon several of his ideas. The investigation itself was performed at the Idaho Division of Highways, Moscow Laboratory by Mr. Dick O. Sanchez and Mr. William A. Sylvies, P. E. Testing was concluded in May, 1977.

#### SUMMARY

The testing was divided into three phases. In the first phase, aluminum, magnesium, and galvanized (zinc) metals were tested for sacrificial protection of reinforcing steel in concrete subjected to de-icing salts. The first phase testing concluded the following:

1. Plain reinforcing bars do require some type of cathodic protection.
2. Magnesium is not suitable material for use as an anode because it reacts much too rapidly and forms an excessive amount of corrosion product.
3. Both zinc and aluminum anodes provide a reasonable degree of corrosion protection for the steel reinforcing bars.
4. Test results indicate that aluminum seems to provide slightly more protection than does zinc and also seems to deteriorate at a slower rate.

In the second phase, sheet zinc and aluminum were further tested for sacrificial protection. A steel wire anode with impressed voltage was tested under similar exposure as in Phase One. Conclusions from the second phase are:



1. Aluminum continues to provide more protection than does zinc and also seems to deteriorate at a slower rate.
2. Impressed current seems to provide excellent protection.
3. Additional means of protection should continue to be evaluated.

On the basis of Phase II results, a field trial of an aluminum sacrificial anode protective system is planned. The installation will consist of an expanded metal sheet anode covering the entire deck and overlaid with a plant mix wearing course.

In Phase III, impressed current cathode protection of steel in concrete was tested. Different anodes of graphite fiber and conductive epoxy coated copper wires were used. Conclusions from the third phase testing are:

1. Test specimens upon which impressed current cathodic protection was used show less corrosion on the steel than the control (unprotected) specimens.
2. Graphite is unaffected by corrosion when used as the anode.
3. Copper wire with conductive coating, when used as the anode, is subject to corrosion and possible breakage if the coating is open in any spot.

## INTRODUCTION

The increasing use of deicing salts on the nation's roads and bridges for the purpose of increasing safety for the traveling public has brought with it other problems, including the greatly increased rate of deterioration of concrete bridge decks.

It is generally agreed that salt, or more specifically, chloride ion, has little or no effect on quality concrete. The presence of the chloride ion in steel reinforced concrete, however, changes the normally protective environment (to steel) in the concrete and allows reinforcing steel to corrode by various mechanisms.

The presence of chloride ion in concrete bridge decks appears to be a function of the amount of deicing salts applied, the quality of the concrete and the thickness of concrete over the steel plus other less influential things. Several lines of investigations are studying the problem of steel corrosion in bridge decks.

Increasing the thickness of concrete cover, covering the steel with various coatings (metallic zinc or epoxy resins), covering the bridge deck with impermeable membranes, overlays of special impermeable concrete and cathodic protection, both impressed current and sacrificial anode systems, are all being tried.

This investigation concerns cathodic protection with most of the effort directed toward the sacrificial anode method of protection.

While it appears that the impressed current method may give more protection, the sacrificial anode method may be much simpler, have no external power requirements, less maintenance, and add less dead weight to the structure being protected.

The actual sacrificial metal alloys for test were chosen mostly by the

commercial availability in the form which appeared convenient for field use:  
(Expanded Metal Mesh)

The concrete in Phase I and II was a standard mix using a 1" nominal maximum size coarse aggregate, 660 lbs/type III High Early cement per cubic yard and a water cement ratio of 0.6. This high w/c ratio was intended to increase the porosity or permeability of the concrete to accelerate the intrusion of chloride ion.

The concrete in Phase III was the same design except that only fine aggregate (sand) was used in the mix. No concrete additives were used in the mixes.

The work started early in 1974 and was completed in May of 1977. As the work progressed, new ideas and changes were incorporated. The work developed into three phases and reports issued on the phases appeared to be reasonably complete.

The remainder of this report consists of these phase reports plus additional remarks and various laboratory supporting data.



## RESEARCH PROJECT 71

### PHASE I

This project was originated at the request of Mr. Robert B. Jarvis, P. E., Bridge Design Supervisor, and has been developed based primarily upon several of his ideas. The investigation itself is being performed at the Idaho Division of Highways, Moscow Laboratory by Mr. Dick O. Sanchez and Mr. William A. Sylvies, P. E.

Eight 6" W x 6" H x 12" L test blocks were made, each with a No. 6 rebar case lengthwise in the middle of the block one inch below the top. The blocks were made and cured in the moist room for two weeks, and then air dried in the laboratory at room temperature for seven weeks. Air drying was used to permit deeper and faster penetration of the 10% salt solution when it was placed on the plant mix surfacing. Anodes were made of perforated sheets of aluminum, magnesium, and steel wire mesh heavily galvanized with zinc. We were unable to obtain sheet zinc at that time. There were two samples of each type -- that is, two with aluminum anodes, two with magnesium anodes, two with zinc plated steel anodes, and two control samples with no anodes. The anodes were simply laid on top of the block, and a one inch thick asphaltic concrete mat laid on top of the anode. A plexiglass enclosure was then placed on top of the asphalt mat to act as a reservoir for a 10% salt solution.

Photos 1 through 5 illustrate a typical test block. The blocks were continuously exposed to the action of the salt solution at room temperature for the first seven weeks starting March 25, 1974. The salt solution was then removed and the blocks placed in a 115° oven for a week. Alternate cycles of one week wet and one week dry were then used during the rest of the investigation.

The anode grids were connected electrically to the steel reinforcing bar by fastening a one inch wide extension of the anode material to the reinforcing bar by fastening a one inch wide extension of the anode material to the reinforcing bar with a stainless steel clamp. Half-cell potential measurements, using a silver-silver chloride electrode, were made on the steel reinforcing bars every two weeks at the end of the wetting cycle. Readings were made one-half hour after disconnecting the anode from the rebar.

A parallel set of specimens of a different type was also made. Three of these, each consisting of a No. 6 steel rebar connected electrically to a single aluminum, magnesium or zinc plated anode, were immersed in 10% salt solution on March 25, 1976. A control specimen consisting only of a piece of No. 6 steel rebar was subjected to the same treatment. (photo 26) Rust was visible on the control rebar in three days, and the bar was very rusty in 22 days. The zinc plated anode was examined after 15 days, and we estimated that 95% of the zinc was gone. Rust became visible on the attached rebar after 39 days. On the aluminum anode specimen, rust was visible on the rebar in nine days. The magnesium anode disappeared in 22 days, but the rebar was coated with a black substance and rust did not appear in 39 days. At 39 days, the rebars in the four specimens were covered with a black film of undetermined composition. (pictures 28, 29 and 30)

The magnesium anodes on the two concrete blocks were so deteriorated at the end of six weeks that testing was discontinued on the two specimens. (pictures 19, 20, 21, and 22) The volume of corrosion products formed by the magnesium anodes was of such magnitude as to appreciably raise the asphalt mat off the concrete block. The magnesium anodes themselves were so deteriorated that the weight of the uncoated metal remaining could not be determined. The steel reinforcing bars were removed from the two concrete blocks on November 20, 1974, six months after testing was discontinued, and the two rebars showed only minor corrosion loss (0.19% and 0.11% weight loss) which was probably

caused by residual salt solution in the blocks after testing was discontinued.

Half-cell potentials on the two zinc anode specimens increased from -230 millivolts to -355 millivolts for the other specimen in  $7\frac{1}{2}$  months. Examination of the first specimen in November, 1974 showed the anode to be moderately corroded with a 20.4% weight loss, while the steel reinforcing bar was only slightly corroded with a 0.36% weight loss. There were no cracks in the concrete block itself.

Half-cell potentials on the aluminum anode specimens increased from -175 millivolts to -325 millivolts for one specimen and from -175 millivolts to -395 millivolts for the other specimen in  $7\frac{1}{2}$  months. Examination of the first specimen on November 20, 1974 showed the aluminum anode to be much less corroded with a 2.5% weight loss than the corresponding zinc anode with a 20.4% weight loss. The steel reinforcing bar in the aluminum anode test specimen was slightly less corroded with a 0.33% weight loss than the corresponding steel reinforcing bar in the zinc anode test specimen with a 0.36% weight loss. There was a 1 1/2 to 2 inch crack in the concrete block itself on the end where the electrical connection was made.

Half-cell potentials on the control specimen increased from -65 millivolts to -450 millivolts for one specimen and from -65 millivolts to -410 millivolts for the second specimen in 7 1/2 months. Examination of one of the specimens in November 1974 showed the steel reinforcing bar was more corroded with a 0.74% weight loss than the corresponding steel reinforcing bar in either the aluminum anode test specimen (with a 0.33% weight loss) or the zinc plated anode test specimen (with a 0.36% weight loss). There was a three inch crack in the concrete block itself on the end opposite from where the electrical connection was made.

The remaining three blocks from Phase I were examined on July 30, 1975.



Half-cell potentials on the zinc anode specimen had increased from -200 millivolts to -430 millivolts in 16 months. Examination of the specimen showed the zinc plated wire anode to be badly corroded with a 70% weight loss, while the steel reinforcing bar was only slightly corroded with a 0.8% weight loss. A faint crack was noted the entire length of the concrete block.

Half-Cell potentials on the aluminum anode specimen increased from -180 millivolts to -530 millivolts in 16 months. Examination of the specimen showed the aluminum anode to be much less corroded with a 3.5% weight loss than the corresponding zinc plated anode with a 70% weight loss. The steel reinforcing bar in the aluminum anode test specimen was very slightly corroded with a 0.2% weight loss. This was only a quarter of the rebar weight loss in the zinc plated specimen. A fine crack extended about half the length of the concrete block.

Half-cell potentials on the control specimen increased from -315 millivolts to -490 millivolts in 16 months. Examination of the steel reinforcing bar showed it had corroded more with a 3.6% weight loss than the corresponding steel reinforcing bar in either the zinc plated anode test specimen or the aluminum anode test specimen. This is shown in Figure 1 which compares the weight loss for all rebars after both 7 1/2 months and 16 months. There was a wide crack the length of the block directly over the rebar and another finer crack about two inches away, both of which showed rust stains. The reinforcing steel was severely rusted and deeply pitted as much as 1/8 inch over the entire surface area exposed to the concrete.

Interim conclusions of Phase I are: 1. Plain reinforcing bars do require some type of cathodic protection. 2. Magnesium is not suitable material for use as an anode because it reacts much too rapidly and forms an excessive amount of corrosion product. 3. Both zinc and aluminum anodes provide a reasonable degree of corrosion protection for the steel reinforcing

bars. Phase I test results indicate that aluminum seems to provide slightly more protection than does zinc and also seems to deteriorate slower.

Half-cell potentials were made with a silver-silver chloride electrode. To convert the voltage readings to copper-copper sulfate equivalent voltage add (-0.155) volts I.E.  $-.230 \text{ volts silver-silver chloride} = -.230 + -.115 = -.345 \text{ volts copper-copper sulfate}$ . A very high impedance voltmeter (a pH Meter) was used with the silver-silver chloride cell.

The test blocks were numbered as follows:

Numbers 1 and 2: Control      No Anodes

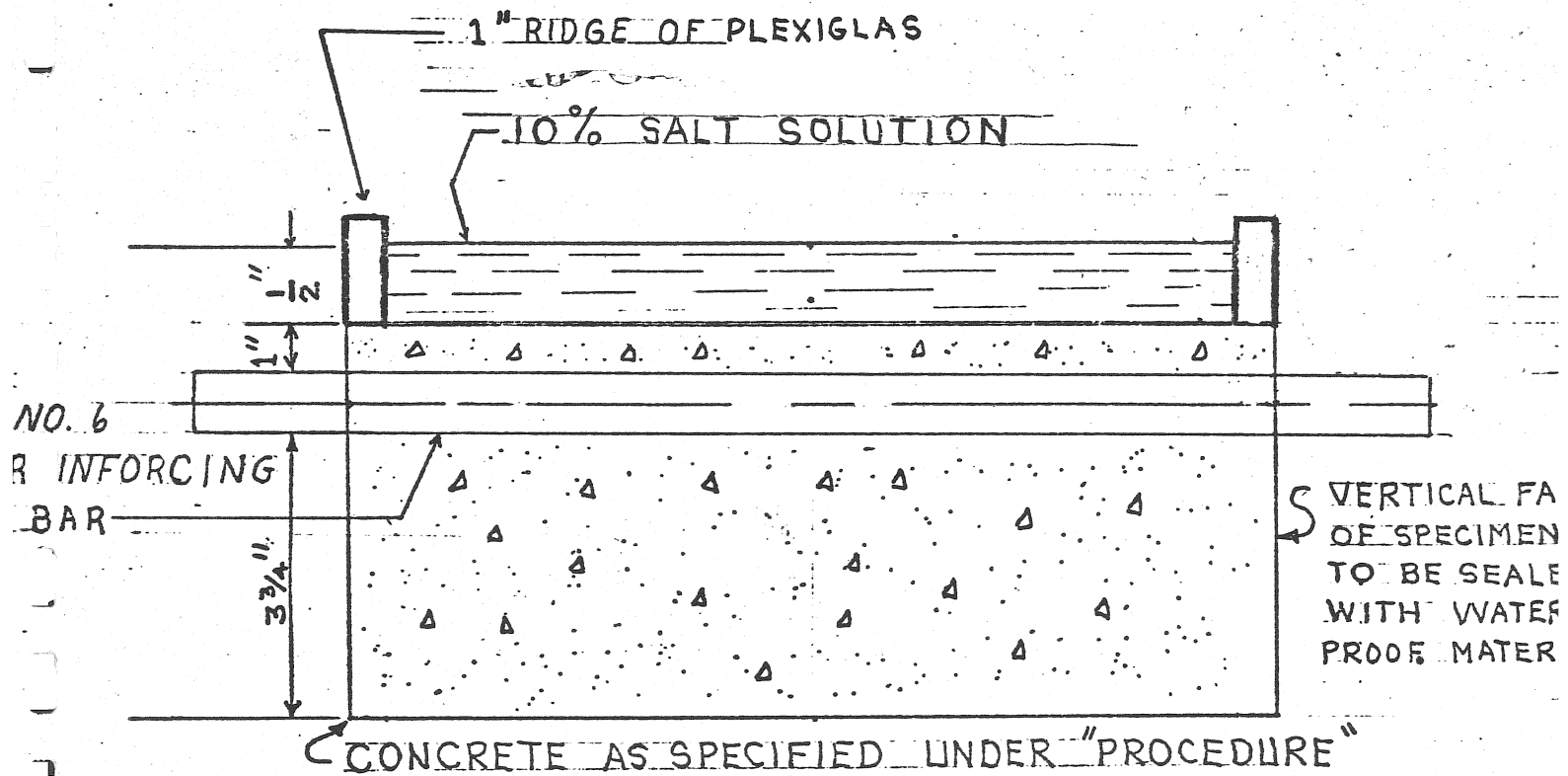
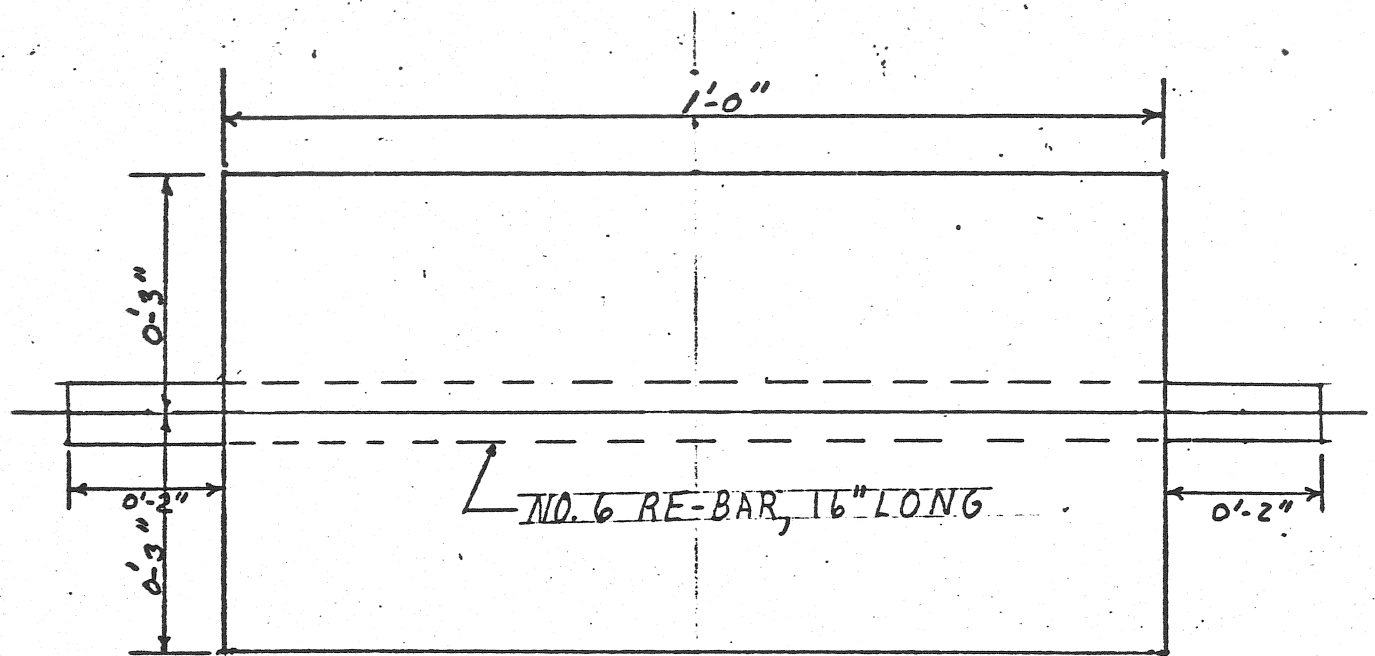
Numbers 3 and 4: Zinc (Galvanized heavy wire screen)

Numbers 5 and 6: Magnesium Anodes

Numbers 7 and 8: Aluminum Anodes

See Appendix A for half-cell potential tabulations.

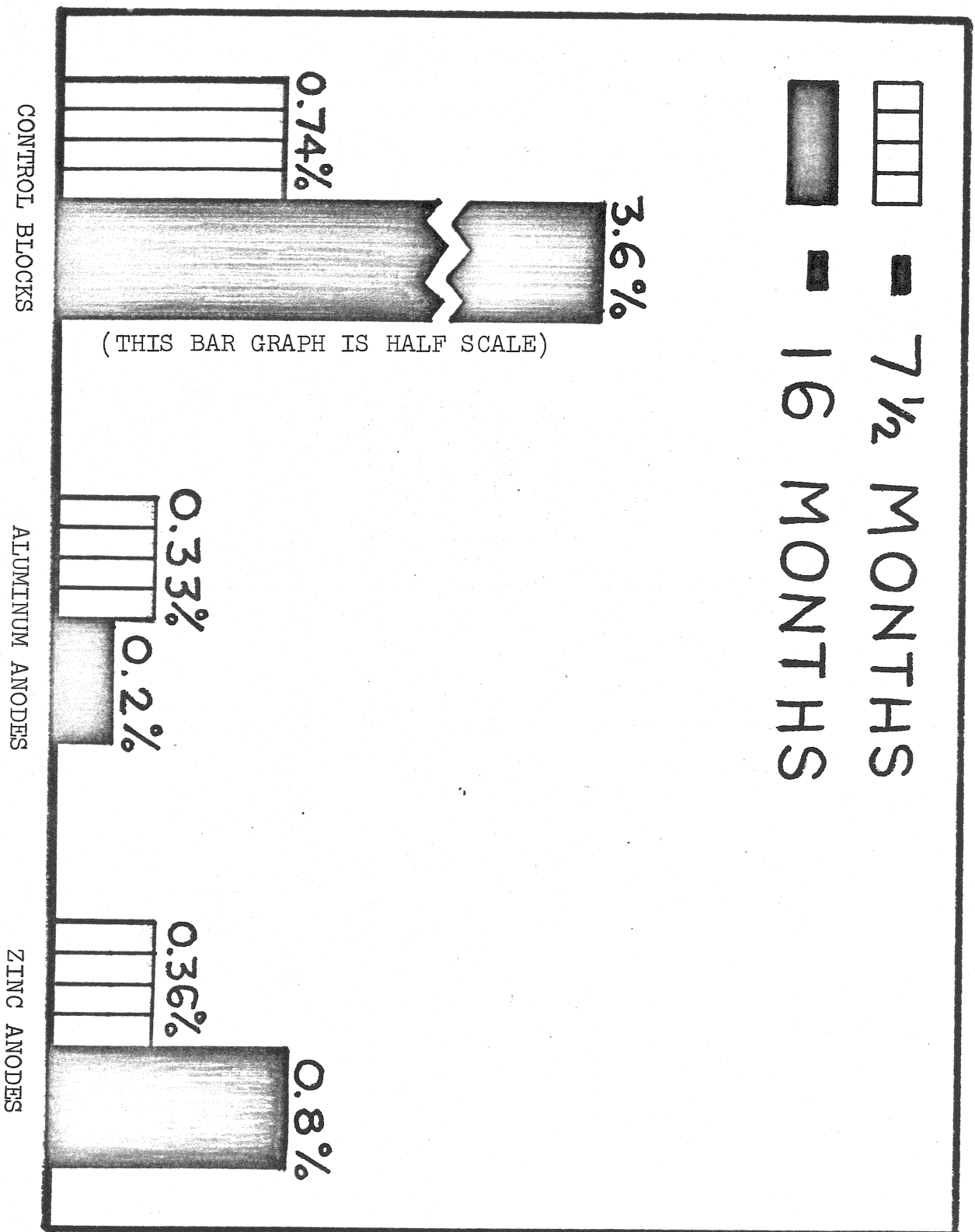
# TEST SPECIMEN



Test Specimen for Investigation of Electrolytic Protection of Reinforcing Steel in Concrete



# WEIGHT LOSS (%)



**Figure 2.** Weight Loss From Steel Rebars in Concrete Test Blocks With No Anodes. (Control Blocks), Aluminum Anodes and Zinc Anodes After 7 1/2 Months and After 16 Months.

## RESEARCH PROJECT 71

### PHASE II

Six 6" W x 6" H x 12" L concrete test specimens were made on December 16, 1974, and then cured and assembled in the same manner as the eight concrete test specimens in Phase I. There were two specimens with sheet zinc anodes, one specimen with an aluminum anode, one specimen with a steel wire mesh grid anode, and two control specimens with no anodes. The specimens were again continuously exposed to the action of a 10% salt solution at room temperature starting February 24, 1975 for seven weeks. As before, the salt solution was then removed and the blocks placed in a 115° F oven for a week. Alternate cycles of one week wet and one week dry were again used during the rest of the investigation.

As before, the anodes were connected electrically to the steel reinforcing bar by fastening a one inch wide extension of the anode material to the reinforcing bar with a stainless steel clamp. For the steel wire mesh grid anode, one of the wires was connected to the rebar, and an impressed voltage of exactly one volt was maintained in the steel wire mesh anode during the entire course of Phase II.

Half-cell potential tests, using a silver-silver chloride electrode, were made on the steel reinforcing bars every two weeks at the end of the wetting cycle. Half-cell potential readings were initially taken starting February 25, 1975 after the anode had been disconnected from the steel bar for thirty minutes. This was to permit the system to stabilize so that steady reading could be taken. However, starting on May 2, 1975, both an initial and a final reading were taken each time. The initial reading was taken immediately after disconnecting the anode from the rebar, while the final

reading was taken thirty minutes after the anode had been disconnected as before.

Steady-state half-cell potentials on the steel wire mesh grid anode specimen increased from -210 millivolts on February 25, 1975 to -430 millivolts on November 21, 1975. On November 7, 1975, it was noticed that the wire anode connection was very loose. By November 21, the wire anode connection had broken. Hence on December 19, the wire mesh grid anode specimen was examined. The anode was badly deteriorated. It had a 45% weight loss and the center wire was in the worst condition. There was no deterioration or sign of rust in the rebar, which had no weight loss. No cracks in the block were noted and splitting the block for rebar observation was more difficult than had been the case in Phase I. After removal of the rebar, no rust was noted on the bar where it was embedded in the concrete.

Steady-state half-cell potentials on the aluminum anode specimen increased from -180 millivolts on February 25, 1975 to -500 millivolts on March 12, 1976. Examination of the specimen on April 20, 1976 showed the aluminum anode to be only slightly corroded with a 2.0% weight loss. The rebar in the specimen showed a 0.43% weight loss. A one inch crack was observed at the rear top edge of the concrete block just above the rebar.

Half-cell potentials on the control specimens increased from -80 millivolts on February 25, 1975 to -440 millivolts on March 12, 1976 for the first specimen, and from -55 millivolts to -425 millivolts for the second specimen in the same period of time. Examination of the two specimens on April 20, 1976 showed the steel rebar moderately corroded with 1.79% and 2.01% weight losses respectively. There was a full length crack in the concrete block over the rebar in both specimens.

Interim conclusions resulting from Phase II are:

1. Aluminum continues to provide more protection than does zinc and also seems to deteriorate at a slower rate.
2. Impressed current seems to provide excellent protection.
3. Additional means of protection should continue to be evaluated.

Half-cell potentials were made with a silver-silver chloride electrode.

To convert the voltage readings to copper-copper sulfate equivalent voltage add (-0.155) volts I.E.  $-.230 \text{ volts silver-silver chloride} = -.230 + -.115 = -.345 \text{ volts copper-copper sulfate.}$

The test blocks were numbered as follows:

A and B: sheet zinc anodes

C : aluminum anode

D : steel wire mesh (for impressed voltage anode)

E and F: control (no anodes)

See Appendix A for half-cell potential tabulations.

## RESEARCH 71

### Phase III

Six 2" W x 2" H x 30" L test blocks were made on January 12, 1976, each with four Number 2 rebars cast lengthwise in the block as shown in Figure 3. The blocks were cured in the moist room for two weeks. They were then removed from the moist room and air dried in the laboratory until March 16, 1976.

Anodes for specimens 20 and 21 were made from unsized AS2 10,000 filament graphite fiber yarn supplied by Hercules Incorporated. Specimens 22 and 23 were control specimens having no anodes. The two anodes for specimen 24 were copper wire coated with TPL-219 carbon black epoxy coating supplied by General Polymers Corporation. The two anodes for specimen number 25 were copper wire coated with PL-220 graphite epoxy coating supplied by General Polymers Corporation. The anodes were simply laid on top of the blocks and a one inch thick asphaltic concrete mat laid on top of the anodes. The blocks were cast with a 1/2 inch thick, 2 inch high concrete rim around the top of the block to provide a reservoir for the 10 percent salt solution. The blocks were again continuously exposed to the action of the salt solution at room temperature for the first six weeks starting March 16, 1976. The salt solution was then removed and the blocks placed in a 115°F oven to dry for a week. The salt solution was then reapplied for a week, removed, and the blocks again placed in the 115°F oven for a week. Alternate cycles of one week wet and one week dry were then used during the rest of this phase of the investigation.

On specimens 20 and 21, the graphite fiber ribbon anodes were fastened to a copper connection by crimping on each end and a piece of copper wire was soldered to the two copper connections on the front end. Another piece of copper wire was soldered between the two top steel rebars. A voltage of exactly 1.0 volts was then impressed on the specimen by fastening the positive ter-

minimal to the top two rebars. The impressed voltage has been maintained on the specimen during the entire course of Phase III.

The copper wire anodes on blocks 24 and 25 were connected by a copper wire soldered between the anodes in each case. The top two rebars on each specimen were also connected by a copper wire soldered to the rebars. A voltage of exactly 1.0 volts was then impressed on both specimens with the positive terminal connected to the anodes and the negative terminal connected to the top two rebars. The impressed voltage has been maintained in the specimen during the entire course of Phase III.

Half-cell potential measurements using a silver-silver chloride electrode have been made on the top two steel reinforcing bars every two weeks at the end of the wetting cycle. Each time, an initial half-cell reading has been taken immediately after disconnecting the anode from the rebar, while a final reading has been taken 30 minutes later.

Six 2" x 2" x 30" blocks were identified as follows:

Block 20 and 21: Graphite Twine Anode

Block 22 and 23: Controls - No Anodes

Block 24 : Copper Wire with Carbon Black Epoxy Coating

Block 25 : Copper Wire with Graphite Epoxy Coating

Potential was measured using a silver-silver chloride cell and the top steel rods. See Appendix A for half-cell potential tabulations.

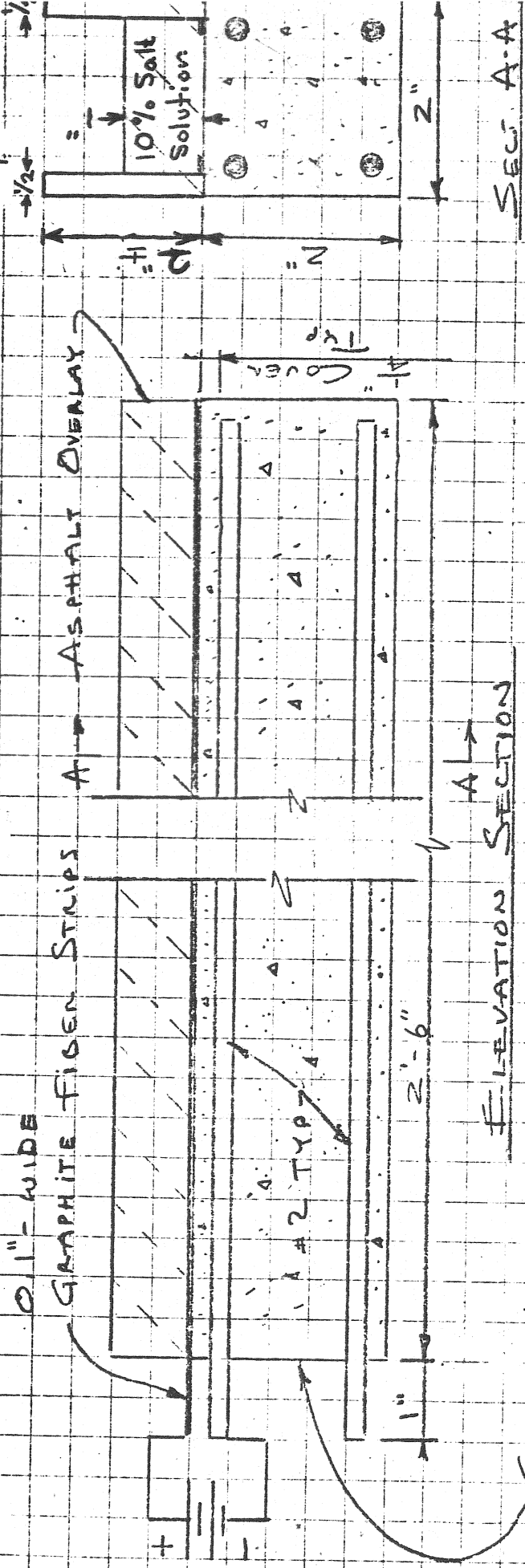
#### DISCUSSION AND CONCLUSION PHASE III

The test conditions are fairly severe. No clear interpretation of the voltage record of the six blocks can be made at this time as the voltage pattern varied, but the weight loss of the rods of the protected blocks (Nos. 20, 21, 24 and 25) when compared on the basis of the test period shows the following:

		<u>% of Weight Lost</u>			
		<u>TOP RODS</u>		<u>BOTTOM RODS</u>	
Block 20 (Protected)	5 Month Exposure	0.08	0.28	0.28	0.17
Block 22 (Unprotected)	5 Month Exposure	0.32	0.47	0.37	0.52
Block 25 (Protected)	5 Month Exposure	0.83	0.15	0.36	0.33
Block 21 (Protected)	13 Month Exposure	0.9	2.1	2.8	3.7
Block 23 (Unprotected)	13 Month Exposure	2.0	1.2	5.3	5.5
Block 24 (Protected)	13 Month Exposure	1.2	0.4	3.4	2.2

At the end of the 13 month exposure period, the protected rods (except in one case) show less loss of metal.





CONCRETE WITH  
1/8" MAX AGGREGATE

NOTE - THE 1/4" COVER DIMENSION AND 0.1" WIDTH OF GRAPHITE FIBER DIMENSION ARE THE ONLY DIMENSIONS THAT ARE AT ALL CRITICAL.

# TEST BLOCKS (MAKE 4) FOR GRAPHITE-FIBER TEST

FIGURE NO. 3

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## PHASE III

TABLE I

The rod anodes have been weighed before and after the test to determine the percent of weight loss. The following tabulation shows these results.

<u>ROD NO.</u>	<u>BOX NO.</u>	<u>WT. BEFORE</u>	<u>WT. AFTER</u>	<u>WT. LOSS</u>	<u>5 MONTH TEST % WT. LOSS</u>
1] Lower	20	194.41	193.87	0.54	0.28
2] Lower		194.37	194.04	0.33	0.17
3] Upper		195.27	195.12	0.15	0.08
4] Upper		193.56	193.01	0.55	0.28
9] Lower	22	194.22	193.31	0.91	0.37
10] Lower		194.90	193.88	1.02	0.52
11] Upper		194.00	193.38	0.62	0.32
12] Upper		194.00	193.08	0.92	0.47
21] Lower	25	194.10	193.41	0.69	0.36
22] Lower		193.89	193.25	0.64	0.33
23] Upper		195.23	194.94	0.29	0.15
24] Upper		195.14	193.52	1.62	0.83
Copper Wire For Box	25	50.20	49.83	0.37	0.74

TABLE II

The rod anodes have been weighed before and after the test to determine the percent of weight loss. The following tabulation shows these results.

<u>ROD NO.</u>	<u>BOX NO.</u>	<u>WT. BEFORE</u>	<u>WT. AFTER</u>	<u>WT. LOSS</u>	<u>13 MONTH TEST % WT. LOSS</u>
5] Lower	21	194.08	188.33	5.75	2.8
6] Lower		195.44	188.09	7.35	3.7
7] Upper		193.34	193.19	0.19	0.9
8] Upper		195.37	191.21	4.16	2.1
13] Lower	23	196.49	186.12	10.37	5.3
14] Lower		194.64	183.97	10.67	5.5
15] Upper		194.13	190.33	3.81	2.0
16] Upper		195.77	193.38	2.39	1.2
17] Lower	24	194.69	188.07	6.62	3.4
18] Lower		194.71	190.48	4.22	2.2
19] Upper		195.10	192.82	2.28	1.2
20] Upper		195.28	194.46	0.82	0.4

## RESEARCH PROJECT

## PHASE I

A P P E N D I X    AHALF CELL VOLTAGE READINGS (-MILLIVOLTS)

TEST DATE	Specimen Numbers							
	1	2	3	4	5	6	7	8
03/27/74	100	80	200	230	230	200	175	175
03/28	270	90	200	220	240	195	180	170
03/29	279	280	200	210	245	190	180	170
04/01	315	300	195	205	245	190	180	175
04/08	325	310	185	205	270	200	195	175
04/16	320	320	180	205	90	200	195	175
04/24	330	310	185	205	80	200	200	170
05/03	335	320	190	205	190	175	205	175
05/10	Start Wet/Dry	340	320	190	205	End	End	200
05/24		350	340	205	215			200
06/07		340	335	200	200			190
06/21		260	370	200	200			195
07/05		365	380	200	205			270
07/19		370	385	205	210			320
08/02		410	400	205	260			340
08/16		410	430	300	310			345
08/30		420	440	340	330			345
09/13		410	425	345	330			325
09/27		415	435	380	330			330
10/11		430	415	400	330			355
10/25		440	425	405	330			335
11/08		450	410	400	355			325
11/22		450	End	395	End			330
12/13		470		370				320
12/27		470		385				320
01/10/75		470		410				335
01/24		505		420				330
02/07		520		400				325
02/21		530		405				320
03/07		505		370				310
03/21		505		370				310
04/04		505		360				320
04/18		530		350				320
05/02		540		415	360			420 300
05/16		545		425	360			430 320
05/30		540		430	380			430 323
06/13		530		410	370			415 315
06/27		525		425	390			405 320
07/18		490		460	430			575 530
		End		End				End

Silver-Silver Chloride Cell Used.

All readings above (Final) were taken 30 minutes after disconnecting the anode, except columns 3 and 7 where after 4-18 initial readings taken immediately after disconnecting the anodes are shown along with the final readings.

## RESEARCH PROJECT 71

## PHASE II

A P P E N D I X      BHALF CELL VOLTAGE READINGS (MILLIVOLTS)

TEST DATE	SPECIMEN					
	A	B	C	D	E	F
Exposed to						
02/25/75 Salt Solution	180	175	180	210	80	55
02/28	185	165	180	210	250	50
03/07	180	140	170	200	230	50
03/14	185	145	165	190	230	50
03/21	185	230	160	195	235	55
03/28	640	200	160	200	225	50
04/04	700	175	150	185	225	50
04/11	670	170	150	180	190	50
04/18	665	160	150	170	210	55
05/02	740 605	640 210	640 210	685 190	280	70
05/16	700 540	580 240	580 240	700 190	280	220
05/30	780 700	660 235	660 235	720 190	310	270
06/13	660 480	590 220	590 220	460 195	310	280
06/27	610 420	610 230	610 230	740 200	340	310
07/18	550 360	610 240	610 240	740 225	375	330
08/01	560 380	590 250	590 250	820 250	390	345
08/15	600 390	610 280	610 280	840 290	390	360
08/29	610 375	570 230	570 230	880 305	375	375
09/11	580 370	560 280	560 280	940 360	380	400
09/26	580 365	500 250	500 250	940 370	385	400
10/10	590 360	520 290	520 290	920 380	390	410
10/24	530 330	490 300	490 300	980 420	370	390
11/07	530 320	520 310	520 310	1.060 420	365	395
11/21	550 330	490 290	490 290	840 430	365	420
12/12	550 430	450 240	450 240	End	400	430
01/02/76	580 425	465 255	465 255		400	430
01/16	580 410	450 270	450 270		415	440
01/30	580 420	470 280	470 280		410	430
02/13	600 440	420 280	420 280		410	420
02/27	585 450	490 300	490 300		440	420
03/12	590 420	430 280	430 280		440	425
	End	End	End		End	End

Silver-Silver Chloride Half Cell Used.

Voltages shown are Initial (Left Column) taken immediately after disconnecting anodes and Final (Right Column) taken 30 minutes later.

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## PHASE III

A P P E N D I X      BHALF CELL VOLTAGE READINGS (-MILLIVOLTS)

<u>Test Date</u>	<u>Specimen Numbers</u>					
	<u>20</u>	<u>21</u>	<u>22</u>	<u>23</u>	<u>24</u>	<u>25</u>
03/17/76	590 255	620 290	460	425	405 400	335 335
03/30	550 315	880 840	630	500	510 490	450 450
04/06	550 315	840 780	540	495	550 535	460 460
04/14	580 330	780 700	445	490	560 540	460 460
04/23	570 380	660 510	470	465	570 530	450 450
05/07	600 410	640 530	480	465	480 450	450 450
05/21	585 500	650 600	500	470	590 530	420 420
06/04	580 510	650 600	510	485	590 530	450 450
06/18	570 530	630 560	525	480	560 515	470 470
07/02	545 425	615 565	535	475	490 450	470 470
07/16	545 430	605 560	525	478	480 455	470 470
07/30	535 425	595 560	520	485	470 445	470 470
08/13	525 430	585 550	510	490	495 460	460 460
08/27	End	600 565	End	465	490 470	End
09/10		580 550		455	510 480	
09/24		590 555		430	460 445	
10/08		590 535		480	470 450	
10/22		575 515		465	455 435	
11/05		560 505		470	460 450	
11/19		525 490		460	460 450	
12/03		535 490		475	450 440	
12/17		510 565		477	460 460	
01/07/77		555 500		483	455 450	
01/21		560 510		470	465 455	
02/04		540 490		455	455 450	
02/18		510 480		445	475 470	
03/04		505 465		430	450 440	
03/18		485 450		440	445 435	
04/01		495 465		390	475 470	
		End		End	End	

Silver-Silver Chloride Half-Cell Used.

Voltages shown are Initial (Left Column), taken immediately and Final (Right Column), taken 30 minutes later.

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